

Can Macro- and Micro-Nutrient Inputs be Decoupled During Coastal Upwelling?

Alexander van Geen
Lamont-Doherty Earth Observatory
Columbia University
Palisades, NY 10964
phone: (914) 365-8644 fax: (914) 365-8154 email: avangeen@ldeo.columbia.edu

John Marra
Lamont-Doherty Earth Observatory
Columbia University
Palisades, NY 10964
phone: (914) 365-8891 fax: (914) 365-8150 email: marra@ldeo.columbia.edu

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<http://www.ldeo.columbia.edu/>

LONG-TERM GOALS

Our goal is to understand the magnitude and origin of iron inputs to coastal upwelling systems. We are specifically interested in whether and when iron input can be decoupled from macro-nutrient inputs, and the impact this has on biological productivity.

OBJECTIVES

Our objective is to map the distribution of high macro-nutrient/low micro-nutrient water masses off the coast of Oregon and to understand the circumstances leading to their formation. We wish to develop appropriate tools for the study of chemistry and biology in dynamic coastal upwelling regimes.

APPROACH

We focus on a 100 km x 300 km area off the coast of Oregon centered on Cape Blanco (43° N), which was sampled during one of Dr. Pat Wheeler's GLOBEC cruises on board RV *Wecoma* between July 4-9, 1999. We developed a sensitive colorimetric flow-injection system to measure iron and nitrate concentrations in surface waters while underway. For Fe, the autocatalytic method of Measures et al. (1995) was adapted to a 10-cm flow-through cell of the type used by Waterbury et al. (1997). Underway at ~11 knots, a stream of surface seawater was pumped onboard through all-teflon tubing and into a class-100 flow bench, where it was sampled every 80 seconds for nitrate and iron. This surface-water sampler also allowed us to collect 120 discrete samples along the underway transects. In addition to high resolution surface mapping, we collected 360 Niskin bottle samples at 45 hydrographic stations that allowed us to determine three dimensional metal and nutrient fields during the cruise.

We also deployed a Chelsea Instruments Fast Repetition Rate fluorometer (FRRf) in flow-through mode during the entire cruise, acquiring data on photosynthetic efficiency every 15 minutes.

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In-situ chemical and biological data were combined with shipboard ADCP (Mike Kosro, OSU), wind data from coastal monitoring stations and SeaWiFS images spanning the cruise to assemble a picture of water-mass evolution from physical forcing through chemical inputs and biological response. Cruise participants included PI Lex van Geen, graduate student Zanna Chase (Fe and nutrients), and co-PI John Marra's technician, Nicole Ventriello (FRRf).

WORK COMPLETED

Since the cruise, we have completed iron nitrate, phosphate and silicate analyses on all discrete surface samples and 13 key vertical profiles. The underway nitrate, iron and FRRf data have been reduced, quality-controlled, and merged with the ship's underway data. We had some clear weather during the cruise and found good SeaWiFS coverage. We have a manuscript in preparation describing the results of this cruise.

RESULTS

We measured iron and nitrate concentrations underway in surface waters and in vertical profiles off the Oregon coast in July, 1999. Surface data are shown in Figure 1 for underway (b and d) and discrete measurements (a and c). Surface-water nitrate was high in cool, recently upwelled water near the coast, as expected. Although the distribution of surface-water iron inferred from the two sets of measurements is similar, it is clear that iron concentrations measured in stored, acidified samples collected from the underway pumping system were in general much higher than underway measurements (Figure 1 c,d). The difference between the two measurements is greatest in shallow, near-shore waters, which are more likely to contain elevated levels of particulate Fe which would be have been partly or completely solubilized by the acidification applied to the discrete samples. In fact, the large difference between the two measurements in some locations, for example near-shore south of Cape Blanco, suggests particulate Fe is the dominant form of iron delivered to surface waters in this area. Surface-water iron was high near shore, in a region of broad continental shelf over Heceta Bank, and in low salinity, high silicate waters of the Columbia River plume, offshore of the NH line (Figure 1, cd). We conclude that sediment and riverine sources dominate the iron input to surface waters off Oregon.

A set of profiles collected along the NH line at the onset of upwelling-favorable winds (Figure 2) illustrates the relationship between sediment resuspension, upwelling, and water-column iron concentrations. All four profiles show coherence between particle concentration, as measured by beam attenuation, and the concentration of dissolvable iron (dFe), again pointing to the importance of particulate iron. The profile at 157 km from shore shows low iron concentrations (< 2.2 nM) throughout the water-column, in agreement with previous profiles offshore of California (Martin and Gordon 1988). The profile at 46 km from shore shows some evidence of sediment input, in the elevated iron concentrations at depth. However, in this depth of water (292 m) resuspended sedimentary Fe has no impact on surface-water concentrations. Two near-shore stations have iron and particle concentration profiles with a mid-depth minimum. We propose that during downwelling conditions, as occurred prior to sampling this station, the bottom boundary layer thickens (Small et al. 1989), and the entire water-column becomes turbid and iron-rich. These profiles are consistent with the penetration of an intermediate layer of clear, iron-poor water onto the shelf with the onset of upwelling. Surface-water Fe enrichment may therefore be the result of BBL thickening during downwelling conditions. Alternatively, the profiles, and the enrichment of Fe in surface waters, may reflect upwelling through the

iron-rich bottom boundary layer which outcrops at the surfzone enriched in iron (van Geen et al. 2000) and is subsequently advected offshore in the surface Ekman layer.

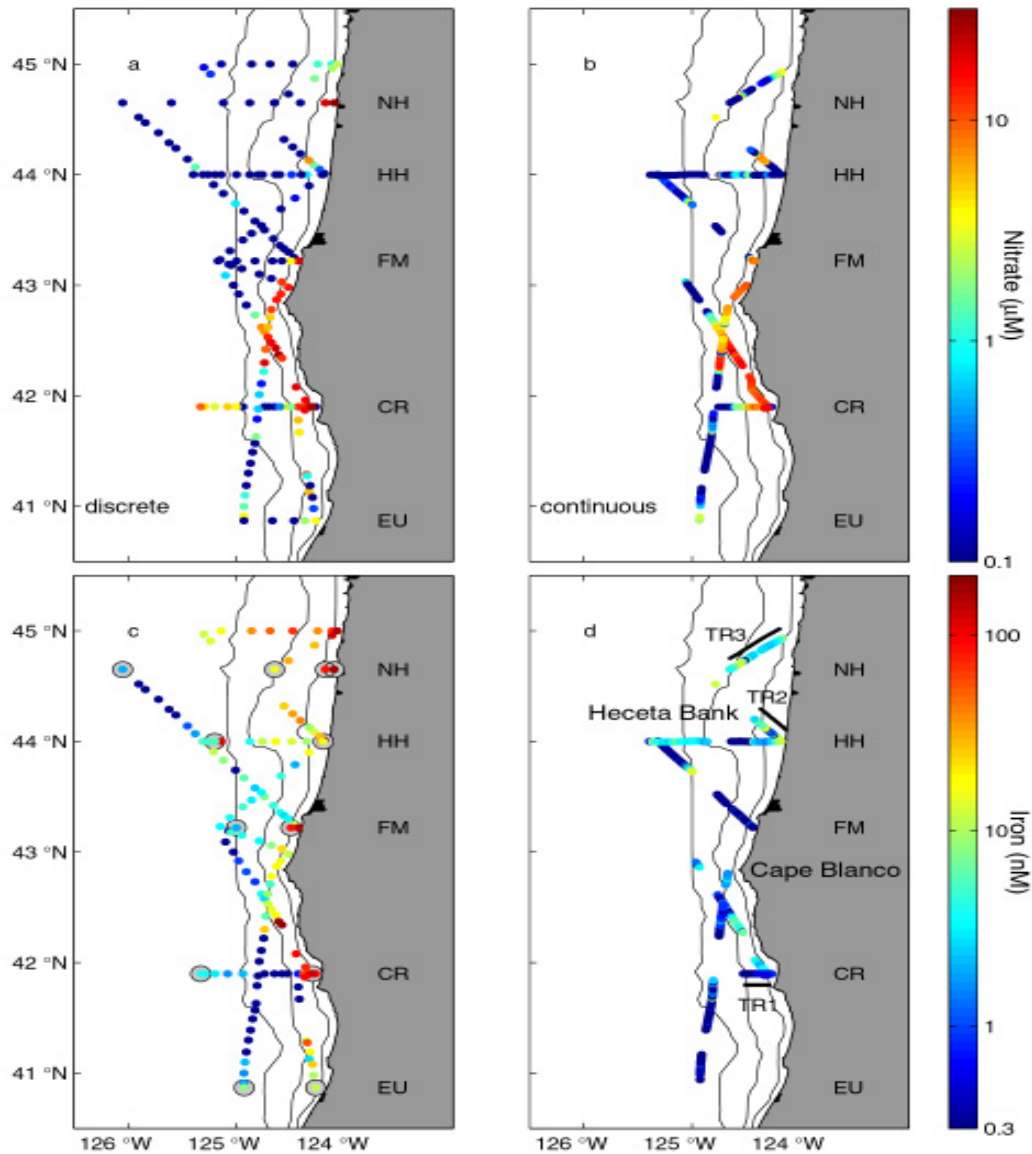


Figure 1: (a and b) Surface-water nitrate + nitrite (μM) and (c and d) iron (nM) concentrations off Oregon during July 3-8, 1999 measured (a and c) in discrete, acidified (pH 2) samples collected from the underway pumping system or surface rosette samples and (b and d) at sea by flow injection analysis, without filtration or acidification. Note the logarithmic color scale. Grey circles in (c) indicate the location of CTD stations where we obtained vertical profiles of NO_3 and Fe. TR1-3 are cross-shelf transects we have examined in more detail with high-resolution underway data.

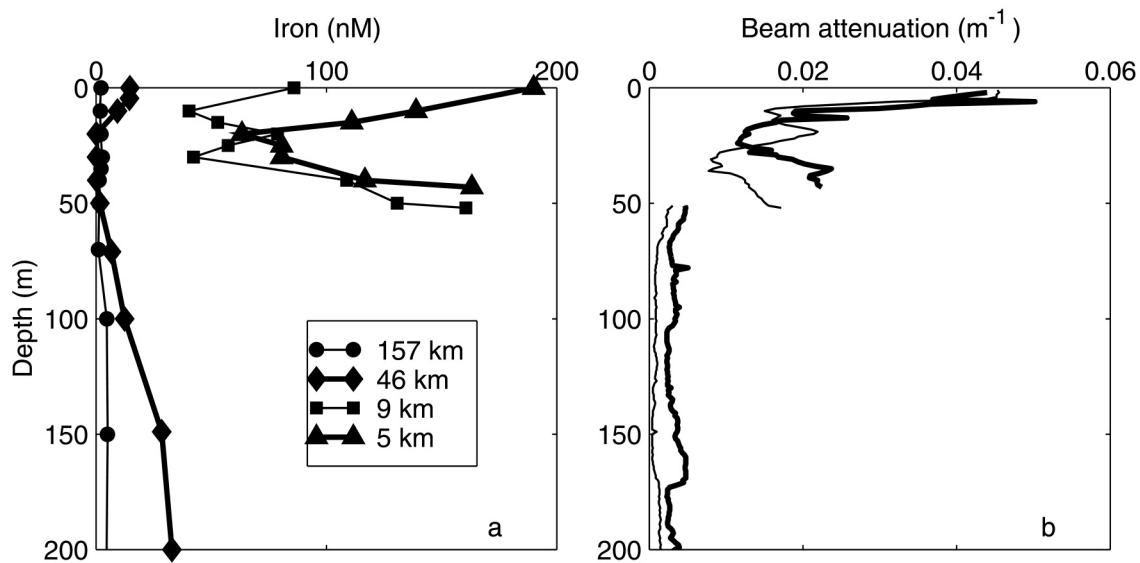


Figure 2: Vertical profiles of (a) iron (nM) and (b) beam attenuation (m^{-1}) from a cross-shelf transect along the NH line (see Figure 1c). For clarity, beam attenuation for the deep profiles (located 157 km and 46 km from shore at a depth of 2881 m and 292 m, respectively) is plotted only for depths below 50 m.

High-resolution underway sampling was able to resolve small-scale spatial variability in macro and micro-nutrient concentrations, and revealed the importance small-scale vertical and horizontal transport in generating this variability. Compared to open ocean environments, iron concentrations- both underway and total- were high throughout Oregon coastal waters. Yet, 55% of our underway observations were of $\text{Fe} < 1 \text{ nM}$. Of samples containing greater than $10 \mu\text{M NO}_3$ (105), 20% (21) had $\text{Fe} < 5 \text{ nM}$. Biological productivity, measured as remotely-sensed chlorophyll, underway *in-vivo* fluorescence and Fast Repetition Rate fluorometry (FRRf), displayed large temporal and spatial variability, which appeared to be driven primarily by physical dynamics. However, at a very coarse scale, the FRRf data are consistent with an influence of iron concentration on the physiological status of the phytoplankton community, even at the high iron concentrations ($> 1 \text{ nM}$) generally found in the study area.

IMPACT/APPLICATION

This study supports the suggestion (Johnson et al., 1999) that Fe input to surface waters depends on the interaction of upwelled water with shelf sediments. We have shown that sedimentary iron, largely in the particulate form, is input to surface waters through wind-induced vertical mixing, upwelling through the bottom boundary layer, and through bottom mixed layer thickening during downwelling conditions. Off Oregon, iron associated with freshwater inputs can also be significant. These results should be of use to those wishing to incorporate iron inputs and cycling into coupled physical-chemical-biological models of productivity in coastal upwelling systems.

TRANSITIONS

The combination of high resolution macronutrient, iron, and fluorescence measurements proved well suited to the patchy nature of this upwelling system. Our approach should have wide application in understanding the processes that govern phytoplankton productivity and its variability in coastal upwelling systems.

RELATED PROJECTS

The approach and methods developed under the current grant will be applied during two upwelling cruises off the Oregon coast in 2001, and one downwelling cruise in 2003, as part of the recently funded CoOP program “Coastal Advances in Shelf Transport (COAST)” (J. Barth, P. Wheeler, J. Allen, Project Leaders). The LDEO component of this collaborative effort is entitled “Iron Input and Wind-Driven Circulation Along the Oregon Coast”.

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